Energy Audit Report

Of **S. B. RESHELLERS,**
KOLHAPUR

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1.0 INTRODUCTION

In November 2011 MB Associates assisted a series of audits of operation – with a view to reducing energy consumption – in the Kolhapur foundry cluster. The audits were carried out by Shivaji University personnel as part of a World Bank-GEF-BEE initiative. MB Associates' role was to assist the Institute for Industrial Productivity (IIP) to provide industry specific technical guidance before and during the audits.

The objective of the project was to develop an understanding of the overall performance of the Kolhapur Cluster, carry out a comparison of that performance and provide guidance as to the methods required for improvement. This should enable the foundries to check and improve their efficiency and consumption of resources and energy.

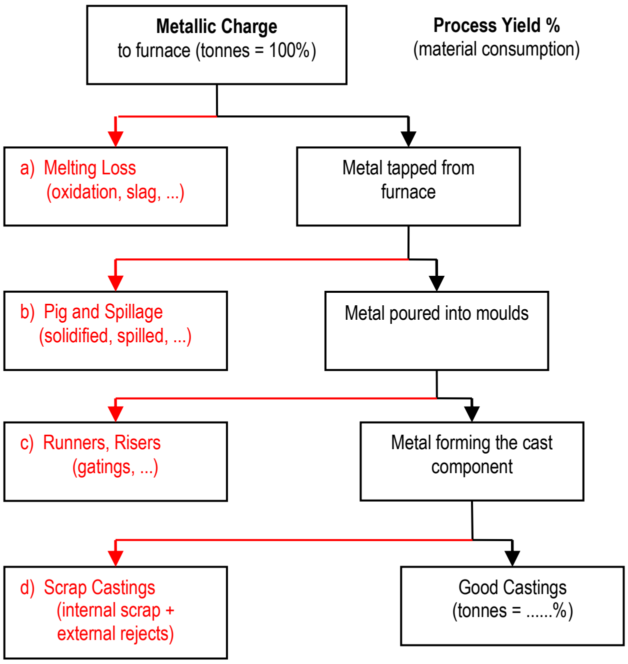
The analysis and the recommendations made in this report are based on the audit data provided by Shivaji University and the information provided by the foundries themselves and observations made during the field visits undertaken in November 2012.

In order for the individual units to better understand the energy audit results and the recommendations made thereof, a brief explanation is provided about Key Performance Indicators (KPIs) in a foundry.

1.1 Key Performance Indicators (KPIs)

1.1.1 Process Yield

This KPI monitors how much of the material processed ends up as good saleable castings. As most of the material which does not end up as good castings is recycled, the loss of material is of minor importance. Much more important is the loss of energy, labour time, and capacity for processing material which does not end up as a saleable product. See below:



Performance:
Tonnes of Good Castings divided by tonnes of liquid melt processed;

This KPI is comprised from 4 sub-indicators

a) KPI 1.1 – Melting loss (%)
b) KPI 1.2 – Pig and spillage (%)
c) KPI 1.3 – Runners and risers (%)
d) KPI 1.4 – Scrap castings (%)

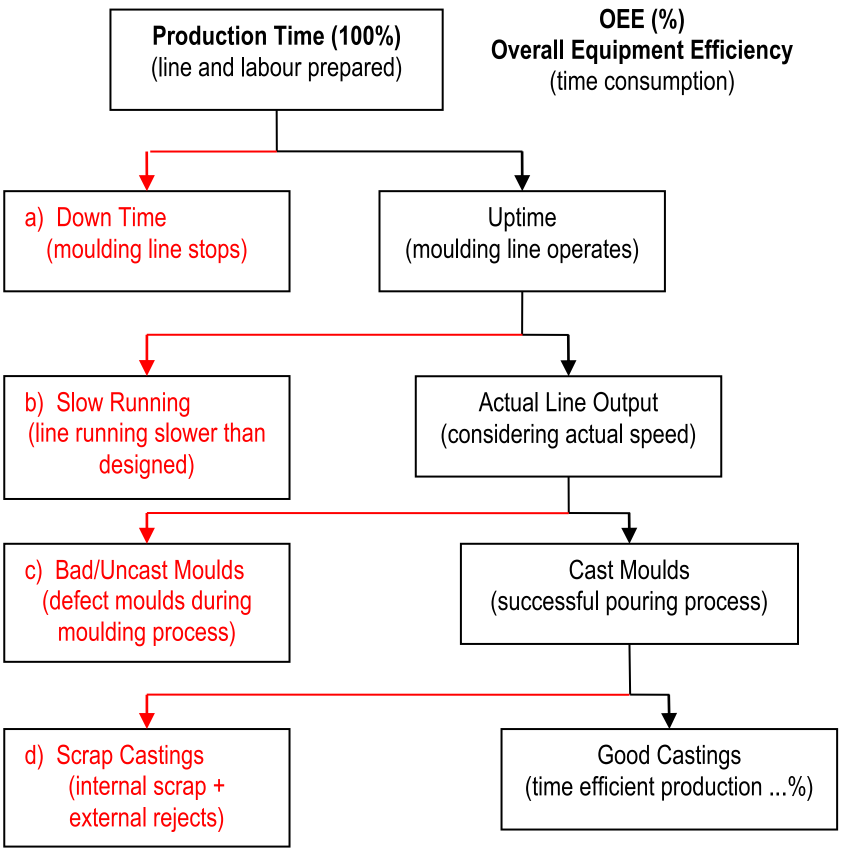
Formula:
KPI 1 = (1-a) x (1-b) x (1-c) x (1-d) x 100%

No	KPI	Definition
1	Process Yield (%)	Material consumption based performance. The weight of net good castings produced as a percentage of the metallic material charged to the melting furnaces; comprised from 4 performance indicators.
1.1	Melting Loss (%)	The material lost during melting (either by oxidation or incorporation into the slag) expressed as a percentage of the metallic material charged to the melting furnaces.
1.2	Pig and Spillage (%)	The amount of liquid metal tapped from the furnace which does not get poured into moulds expressed as a percentage of the liquid metal tapped.
1.3	Runners and Risers (%)	The weight of liquid metal poured into the mould which does not form a casting expressed as a percentage of the liquid metal poured into that mould.
1.4	Scrap Castings and Rejects (%)	The weight of scrap castings (including customer returns) expressed as a percentage of the weight of gross castings produced.

1.1.2 Effective Production (OEE)

Time consumption based performance also known as Overall Equipment Effectiveness indicates the gap between actual and ideal performance.

The time during which the plant produces good saleable castings expressed as a percentage of the time that the plant was available for production. See below:



This KPI is comprised from 4 sub-indicators

a) KPI 2.1 – Down Time (Moulding) (%)
b) KPI 2.2 – Slow Running (%)
c) KPI 2.3 – Bad Moulds (%)
d) KPI 2.4 – Scrap and Rejects (%)

Formula:

KPI 2 = (1-a) x (1-b) x (1-c) x (1-d) x 100%

No	KPI	Definition
2	OEE (%) – Overall Equipment Efficiency	Time consumption based performance. The time during which the plant produces good saleable castings expressed as percentage of the time that the plant was available for production; comprised from 4 performance indicators.
2.1	Downtime (Moulding) (%)	The time that a moulding facility is not operating due to breakdowns or operational reasons expressed as a percentage of the total time available for production (often called the net operating time).
2.2	Slow Running (%)	The production time lost by operating a moulding facility at a speed below the design capacity or calculated output expressed as an equivalent percentage of the net operating time.
2.3	Bad Moulds (%)	The number of moulds that are not poured expressed as a percentage of the total number of moulds produced.
2.4	Scrap and Rejects (%) (internal scrap and external rejects)	The weight of scrap castings (including customer returns) expressed as a percentage of the weight of gross castings produced.

1.1.3 TEEP (Total Effective Equipment Performance)

No	KPI	Definition
3	TEEP (%) – Total Effective Equipment Performance	Time based capacity utilisation. Total effective equipment performance (TEEP) measures OEE effectiveness against calendar hours, i.e. 24 hours per day, 365 days per year. Total Effective Production per annum expressed as a percentage of the total plant capacity if operating for 24 hours per day, 365 days per year.

1.14 Energy Consumption

The KPIs referring to energy consumption are monitored for two levels as some 75% of total energy consumption is usually consumed already only in the melting plant and measures for improvement can be concentrated on this department:

- KPI 4.1 – energy consumption in melting
- KPI 4.2 – energy consumption in foundry

The energy consumption includes all types of energy such as electric power, coke (i.e. when combustion melting in cupola furnaces), gas and oil. The energy consumption is expressed in kWh.

No	KPI	Definition
4	Energy Consumption	Energy is one of the most important cost factors apart from raw material and in melting the energy supply often is a limiting capacity factor.
4.1	Energy Consumption in Melting (Melting Efficiency) (kWh/tonne melt)	Furnace power consumption (kWh) divided by the tonnage of metallic material charged to the furnaces *(the melting consumes some 75% of the total foundry energy demand; a good performance of the melt shop saves money and capacity).*
4.2	Energy Consumption in Foundry (kWh/tonne good castings)	Total power consumption (kWh) in the foundry departments divided by the tonnage of net good castings produced *(the cost impact of energy consumption is a competitive mark)*.

1.1.5 Sand Consumption

The performance of sand consumption is monitored with 2 KPIs:

- new (fresh) sand consumption per tonne of good castings (indicates design of casting process)
- rate of sand regeneration (indicates how much sand must be dumped)

No	KPI	Definition
5	Sand Consumption	The sand utilised for making the moulds is supposed to be recycled and regenerated as much as possible. A perfect designed and operated sand regeneration plant will reduce costs for sand purchase and also improve quality of castings.
5.1	Fresh Sand Consumption (tonnes sand/tonnes good castings)	The weight of new (fresh) sand used divided by the tonnage of net good castings produced. This indicator includes sand for moulding as well as sand for core making.
5.2	Rate of Sand Regeneration (%)	The percentage of sand that is re-used at each moulding cycle (as an average of all moulding cycles included in the sampling period).

1.1.6 Labour Productivity

No	KPI	Definition
6	Labour productivity (man hours/tonnes good castings)	Apart from the overall productivity a lean organisation and a high grade of automation have the impact on labour productivity. The total number of man hours worked (excluding management and supervisory hours) divided by the tonnage of net good castings produced.

2.0 S. B. RESHELLERS

2.1 General Description

Annual Tonnage – 8,000 tonnes per annum.

Melting is carried out by means of three divided blast cupolas of 30–36" diameter.

Moulding is carried out by hand using a chemically bonded system. Core making employs a similar method.

The plant operates 3 shifts for 6 days per week. During the period May – October melting takes place every day. For the remainder of the year melting occurs on 4 days per week.

2.2 Product Mix

The 8,000 tonnes per annum produced by S. B. Reshellers can be divided into two production categories as follows:

GHGE (Grey Iron Hand Moulding General Engineering)	–	7,920 tonnes (99.0%)
DHGE (Ductile Iron Hand Moulding General Engineering)	–	80 tonnes (1.0%)

The General Engineering classification can be divided into

Roll Production	–	87.5%
Machine Tool Beds	–	12.5%

An explanation of the categories is given in Figure 1.

2.3 Audit Results

2.3.1 Process Yield

During the audit period some 26,910 kg of metallics was charged to the cupola. The coke charged during this period represented 12.0% of the metallics charged to the cupola. Allowing for a proportional allocation of the bed coke, the total coke consumed was 14.7% of the metallics charged to the cupola.

The amount of liquid metal tapped from the cupola was not recorded but the amount of metal poured into the moulds was. Since this weight was 23,981, some 2,929 kg (10.9%) was lost as melting loss and pig and spillage. It is believed that the majority of this was melting loss.

Of the 23,981 kg of metal in the mould 3,022 kg was runners and feeders, giving a box yield of 87.4%, and 20,959 kg of gross castings.

The average scrap rate of 5.0% results in a net good saleable casting weight of 19,911 kg.

Thus some 74.0% of the weight of the material charged to the cupola resulted in castings that could be sold. A representation of the calculation of the Process Yield – where data is available – is given below.

Process Yield Calculation			
Material Charged	26,910	100%	100%
Metal Loss	N/R	N/R	
Liquid Metal	N/R	N/R	N/R
Pig and Spillage	N/R	N/R	
Metal in Moulds	23,981	N/R	89.1%
Runners & Feeders	3,022	12.6%	
Gross Castings	20,959	87.4%	77.9%
Scrap & Rejects	1,048	5.0%	
Net Good Castings	19,911	95.0%	74.0%
Process Yield – 74.0%			

2.3.2 Effective Production

The average production capacity of the moulding facility is 8 moulds per day. No breakdowns or stoppages were reported

In the previous 24 hours before the audit a total of 7 moulds were produced. This represents only 87.5% of the potential available.

Bad moulds were reported at 0.1% and the scrap level was 5.0% – see above.

Therefore the Effective Production for the plant was 81.3%. This means that the plant produced saleable castings for only 81.3% of the available moulding capacity operating time. The calculation of Effective Production is given below.

Effective Production Calculation

Production Time	8.0	100%	100%
Downtime	0	0%	
Operating Time	8.0	100%	100%
Slow Running	1.0	14.3%	
Moulding Output	7.0	85.7%	85.7%
Bad Moulds	0	0%	
Good Moulds	7.0	100.0%	85.7%
Scrap Castings	0.4	5.0%	
Good Production	6.6	95.0%	81.3%

Effective production – 81.3%

2.3.3 TEEP

The plant operates at 2 shifts per day totalling 620 shifts per year. This equates to 4,960 hours or a plant utilisation of 56.6%. However, when the plant is operating the Effective Production is only 81.3% Thus the real plant utilisation or TEEP (Total Equipment Effective Production) is only 46.0% (56.6% x 81.3%). This means that the plant operates in such a way that it only uses 46.0% of its total capacity.

2.3.4 Energy

i) *Melting* – the cupolas consumed coke at the rate of 14.7% of the charged weight. Coke with an ash content of 11.9% has an energy equivalent of 7,975 kWh per tonne. Therefore the coke consumed during melting is equivalent to 1,172 kWh per tonne charged

ii) *Overall Consumption* – the total energy consumed can be expressed as follows:

Cupola Coke	31,538 kWh
Other Processes electricity	280 kWh
	31,818 kWh

During the time of the audit 19.911 tonnes of net good castings were produced, giving a total energy consumption of 1,598 kWh per tonne of good castings.

2.3.5 Sand

New sand consumption was 0.98 tonnes per tonne of good castings. Of this, 0.2 tonnes was used for core making.

Some sand was re-used as backing sand which equates to a sand reclamation of 22.5%, although no real effective sand reclamation was carried out.

2.3.6 Productivity

A total of 334,800 man hours was worked to produce 8,000 tonnes of finished castings. This equates to a productivity level of 41.9 man hours per tonne of good castings.

The ratio of direct workers to indirect workers was 7.9.

2.4 Comparison of Results

In order for S. B. Reshellers to obtain the maximum benefit from the audit, their data will be compared below to other foundries.

2.4.1 Kolhapur Cluster

In the table below the S. B. Reshellers audit data is compared to the average of all of the Kolhapur audit results.

S. B. Reshellers vs. Kolhapur Cluster		
	S. B. Reshellers	**Kolhapur Cluster**
Melting Loss	N/R	6.8%
Pig & Spillage	N/R	4.6%
Runners & Feeders	12.6%	19.7%
Scrap & Rejects	5.0%	4.6%
Process Yield	74.0%	68.1%
Downtime	Nil	Nil
Slow Running	14.3%	50.0%
Bad Moulds	0.1%	2.4%
Scrap & Rejects	5.0%	4.6%
Effective Production	81.3%	46.6%
TEEP	46.0%	28.8%
Energy Consumption Per Tonne Melted	1172 kWh	1057 kWh
Per Tonne Good Castings	1598 kWh	1770 kWh
Sand Consumption New Sand/tonnes castings	0.98 t	0.50 t
Cores/tonnes castings	0.20 t	0.08 t
Sand Reclamation	22.5%	59.0%
Productivity Man hours/tonnes castings	41.9	48.9
Direct Ratio	7.9	4

However, the above table compares the S. B. Reshellers performance with other foundries in the area which have different products and production methods. To gain a more realistic guide to the S. B. Reshellers performance it must be compared to that of similar foundries.

2.4.2 Similar Foundries

In the table below the S. B. Reshellers performance data is compared to that of similar foundries in other parts of the developing world (both average and best practice) and Western Europe.

S. B. Reshellers Performance Comparison

		Developing Countries		Western Europe	
	S. B. Reshellers	Average Performance	Best Practice	Average Performance	Best Practice
Melting Loss	N/R	7.7%	1.0%	2.0%	1.0%
Pig & Spillage	N/R	1.5%	1.0%	3.5%	3.0%
Runners & Feeders	12.6%	25.9%	13.4%	30.1%	27.6%
Scrap & Rejects	5.0%	8.3%	3.9%	2.5%	2.0%
Process Yield	74.0%	61.8%	81.6%	64.5%	68.1%
Downtime	Nil	21.1%	12.4%	5.0%	2.5%
Slow Running	14.3%	8.6%	0.1%	12.5%	10.1%
Bad Moulds	0.1%	1.4%	0.5%	0.5%	0.2%
Scrap & Rejects	5.0%	8.3%	3.9%	2.5%	2.0%
Effective Production	81.3%	65.2%	83.7%	80.6%	85.7%
TEEP	46.0%	15.4%	22.3%	33.7%	37.7%
Energy Consumption Per Tonne Melted	1172 kWh	1443 kWh	899 kWh	625 kWh	620 kWh
Per Tonne Good Castings	1598 kWh	3585 kWh	1533 kWh	1448 kWh	1301 kWh
Sand Consumption New Sand/t castings	0.98 t	1.35 t	0.43 t	0.41 t	0.37 t
Cores/t castings	0.20 t	N/R	N/R	N/R	N/R
Sand Reclamation	22.5%	88.5%	95.3%	91.0%	93.0%
Productivity Man hours/t castings	41.9	167.3	24.1	30.1	25.1
Direct Ratio	7.9	N/R	N/R	N/R	N/R

The data above applies to medium sized foundries using hand/floor moulding techniques to produce large general engineering castings in both grey and ductile iron. The term "Developing Countries" applies to countries such as Brazil, Russia and Mexico.

It should be noted that scrap levels are quoted in terms of the quality standards prevailing in the country of the foundry concerned. For instance what is a good casting in Kolhapur may not be a good casting in the UK or Germany.

2.5 Conclusions and General Comments

2.5.1 Process Yield

The losses in the cupola and for pig and spillage total some 10.9% of the charged material. The majority of this is thought to be melting loss. Figures for combined melting loss and pig and spillage for similar plants in other parts of the world would be 9.2% for developing countries and 5.5% in Western Europe. The main reason for such a high melting loss figure is considered to be associated with the cupola operation:

- incorrectly designed DB cupola (wrong size and spacing of tuyeres)
- blast rate and fan pressure not matched to cupola diameter and wind belt size
- the poor condition of the cupola – the one in operation had a badly corroded upper shell
- the stack charge level was operated too low which increases oxidation potential and reduces the possibility to pre-heat the materials on the stack efficiently.

The above issues are also responsible for the high charge coke consumption of 12.0%. A properly designed cupola would reduce the coke usage by some 25%.

Scrap and reject levels for the plants are 5.0% compared to the average for the Kolhapur Cluster of 4.6%. The equivalent levels for similar foundries elsewhere would be 8.3% for developing countries and 2.5% in Western Europe.

The overall process yield figure for S. B. Reshellers of 74.0% compares favourably with similar foundries in other developing countries (61.8%) and with Western European foundries (64.5%).

2.5.2 Effective Production

No downtime was recorded for the plant. The moulding facility should produce some 8 moulds per day. During the day before the audit some 7 moulds were produced. This represents only 85.7% of the potential plant capacity.

There was an estimated bad moulds figure of 0.1% which is considered to be a good performance for this type of facility. This compares to an average of 2.4% for the Kolhapur Cluster, 1.4% for developing countries and 0.5% for Western Europe.

Taking into account the scrap level, the Effective Production of the plant is 81.3% which compares well with other foundries in the Kolhapur Cluster (average 46.6%) and with similar foundries in other developing countries (65.2%) and with those in Western Europe (80.6%)

2.5.3 Other Parameters

The energy consumed during melting was 1,172 kWh/tonne which compares with the Kolhapur average of 1,057 kWh/tonne The equivalent figure for other developing countries would be 1,443 kWh/tonne and for Western Europe 625 kWh/tonne. An important factor in the high energy consumption for melting is the incorrect design of the cupola and the ancillary plant, as well as the poor condition of the existing cupola, as indicated above.

The overall energy consumption per tonne of finished castings is slightly high at 1,598 kWh/tonne compared to Western Europe at 1,448 kWh/tonne. The average figure for all of the plants audited in the Kolhapur Cluster is 1,770 kWh/tonne

The sand consumption figure for the plant is high at 0.98 tonnes per tonne of castings. This compares to 0.50 for the other foundries in the Kolhapur Cluster, 1.35 for developing countries and 0.41 for Western Europe. The high figure at S. B. Reshellers is a function of the low level of re-use of the sand and effectively no real sand reclamation system. Only 22.5% of the sand is re-used – mainly as backing sand – compared to 59.0% as a general average for the Kolhapur Cluster. Similar foundries in other developing countries would operate at 88.5% reclamation. The figure for Western Europe would be 91.0%.

The recorded level of productivity for the plant is 41.9 man hours per tonne of good castings. Under the circumstances of production at the plant this is considered to be quite a good figure and compares to the overall average for the Kolhapur Cluster of 48.9. The equivalent figure for a similar foundry in Western Europe would be 30.1 man hours per tonne.

Overall plant utilisation (TEEP – 46.0%) is quite good for this type of installation.

2.6 Potential Improvements

A re-design of the cupola and blowing system could:

- reduce coke consumption
- reduce melting loss
- improve metal temperature
- increase melting rate
- reduce scrap levels

- reduce overall energy consumption per tonne of finished castings.

Since material costs represent 51.5% of the total operating costs of the foundry, a reduction in melting loss of 3% represents a reduction in total operating costs of 1.5%.

From the figures provided, coke appears to contribute some 17% of the operating costs so at the same time a reduction in coke consumption of 25% would reduce the total operating costs by 4.3%. Thus improving the design of the cupola can add a minimum of 5.8% on the bottom line, which for a foundry of this type probably doubles the profit margin.

S. B. Reshellers should also install a sand reclamation plant. This would enable – with the appropriate binder system – to reclaim some 90.0% minimum of the sand used. This would greatly reduce sand consumption and therefore further reduce material costs.

Figure 1 Product and Manufacturing Method Classification

Grey iron product categories

Automatic moulding

GABH = automotive engine blocks and cylinder heads
GAAO = automotive other
GAAG = agriculture
GAMI = mining

Mechanised moulding

GMBH = medium sized engine blocks and heads (energy generation)
GMAG = agriculture
GMMI = mining
GMGE = general engineering

Manual (hand) moulding

GHBH = large size engine blocks and heads (energy generation)
GHMI = mining
GHGE = general engineering

Ductile iron product categories

Automatic moulding

DAAU = automotive other
DAGE = general engineering

Mechanised moulding

DMAU = automotive
DMGE = general engineering

Manual (hand) moulding

DHEN = energy generation components
DHCO = compressor components
DHGE = general engineering

Steel product categories

Automatic moulding

SARC = railway components (c)
SAMM = mining components (m)
SAAC = commercial vehicles (c)
SAGC = general engineering

Mechanised moulding

SMRC = railway components (c)
SMMM = mining components (m)
SMPC = pumps and valves (c)
SMPS = pumps and valves (s)
SMGC = general engineering (c)
SMAC = commercial vehicles (c)

Manual (hand) moulding

SHMM = mining components (c)
SHPC = pumps and valves (c)
SHEA = energy components (a)
SHGC = general engineering (c)

c = carbon steel, s = stainless steel
m = manganese steel, a = high alloy steel